

Solar neutrino background in neutrinoless double beta-decay searching for experiments

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Background of germanium and xenon detectors due to the elastic scattering of 8B solar neutrinos on electrons have been calculated. The background is 4.6×10^{-4} counts/(keV·t·y) that defines the sensitivity of double beta-decay experiments at a level $T_{1/2}^{0\nu\beta\beta} \approx 4 \times 10^{27}$ y and it corresponds to effective majorana mass $|< m_{\nu_e} >| \approx 23.5$ meV. This limit after a half of one year of measurements for 10 tons natural Xe detector will be obtained.

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Nowadays neutrino is known to have non zero rest mass.

Super-Kamiokande [1], SNO [2], KamLAND [3] and radiochemical solar neutrino experiments [4], [5], [6] give direct confirmation of neutrino oscillation and as a consequence the existence of non zero neutrino rest mass. Such type of experiments yields information on the differences for squared neutrino mass eigenvalues and mixing angles.

Neutrinoless double beta decay ($0\nu\beta\beta$)

$$^A_Z X \rightarrow ^A_{Z+2} X + 2e^- \quad (1)$$

is characterized as a sensitive tool used both in physics beyond the standard model and in reconstruction of the neutrino mass spectrum.

To obtain the absolute neutrino mass estimations next-generation of $0\nu\beta\beta$ experiments at large scale detectors for rare events (neutrinoless double beta decay, dark matter and low energy solar neutrino real time measurements), have been proposed [7, 8, 9, 10], such as GENIUS, MAJORANA, EXO and XMASS.

These experiments are based on the search for the processes

$$^{76}Ge \rightarrow ^{76}Se + 2e^-, ^{136}Xe \rightarrow ^{136}Ba + 2e^- \quad (2)$$

It is proposed to obtain a limit on the effective Majorana mass $m_{\nu} \approx 15$ meV, which corresponds to $T_{1/2}^{0\nu}(0_i^+ \rightarrow 0_f^+) \approx 10^{28}$ y, while the lowest current one is $|< m_{\nu_e} >| \approx 350$ meV [11].

The effective Majorana mass of neutrino defines half-life of the process (2) without contributions from right-handed currents [13]

$$T_{1/2}^{0\nu}(0_i^+ \rightarrow 0_f^+)^{-1} = \frac{|< m_{\nu} >|^2}{m_e^2} \times G^{0\nu} \times M_{0\nu}^2 \quad (3)$$

where

$$|< m_{\nu} >| = |U_{e1}|^2 m_1 + |U_{e2}|^2 \sqrt{\Delta m_{21}^2 + m_1^2} e^{i\phi_2} + |U_{e3}|^2 \sqrt{\Delta m_{32}^2 + \Delta m_{21}^2 + m_1^2} e^{i\phi_3}$$

is the effective majorana mass of neutrino, closely related with parameters of neutrino oscillation experiments. Here $M_{0\nu}$ is $(0\nu\beta\beta)$ nuclear matrix element, which can be calculated, while U_{ei} are elements of the neutrino mixing matrix, and $\Delta m_{ij}^2 = m_i^2 - m_j^2$, where m_i are neutrino mass eigenstates, ϕ_i denote relative Majorana phases connected with CP violation, and $G^{0\nu}$ is the phase space integral. The experimental signature of the neutrinoless decay of ^{76}Ge is a peak at $Q_{\beta\beta}(^{76}Ge) = 2039.006(50)$ keV [14] and this value together with full width at half maximum (FWHM) defines region of interest (ROI) of these experiments. The background for these experiments should be at a level of 0.1 counts/(keV·t·y) (the best present one is 60 counts/(keV·t·y) [15]). For ^{136}Xe we have $Q_{\beta\beta}(^{136}Xe) = 2480$ keV and FWHM ≈ 60 keV in ROI as was declared in EXO and XMASS proposals.

Solar neutrino flux and two neutrino double decay mode represent unremovable background components in such type of experiments making the recoil electron signal undistinguishable from the two electron one in a germanium or xenon detector.

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The recoil electron energy of the elastic scattering (ES) process

$$\nu + e^- \rightarrow \nu + e^- \quad (4)$$

is detected through ionization produced in the detector for searching for neutrinoless double beta decay. 8B and hep neutrinos with energy up to 15 MeV and 18.8 MeV respectively can give background events into ROI. Flux value of hep neutrinos in comparison with 8B is negligible and it will not be used in our analysis. Background from $^{76}Ge(\nu, e^-)^{76}As$ reaction, which is inverse beta decay, is negligible due to nuclear level characteristics of ^{76}As nucleus. For calculations of count rate in the region of interest standard 8B solar neutrino spectrum was taken from [17]. Differential neutrino electron elastic scattering cross section was taken from [18].

$$\frac{d\sigma}{dT} = \frac{2G^2m_e}{\pi} \left[g_l^2 + g_R^2 \left(1 - \frac{T}{E_\nu} \right)^2 - g_l g_R \frac{m_e T}{E_\nu} \right] \quad (5)$$

where $g_l = \pm \frac{1}{2} + \sin^2\theta_W$; $g_R = \sin^2\theta_W$, $\sin^2\theta_W = 0.23117$; with sign plus corresponding to ν_e , and sign minus to $\nu_{\mu,\tau}$; G is the Fermi constant. Cross section was calculated as

$$\sigma_{\nu_i}(^8B) = \int_0^{E_\nu^{MAX}} \left(\int_0^{T_{max}} \frac{d\sigma_{\nu_i}(T, E_\nu)}{dT} dT \right) \phi^{B-8}(E_\nu) dE_\nu \quad (6)$$

where $T_{max} = \frac{E_\nu}{1+m_e/2 \times E_\nu}$ is maximal kinetic energy of a recoil electron for neutrino with energy E_ν , and $i = e, \mu, \tau$.

Using 8B neutrino fluxes measured in SNO experiment [2]

$$\phi^{CC}(\nu_e) = (1.76 \pm 0.07(stat.)_{-0.11}^{+0.12}(syst.) \pm 0.05(theor.)) \times 10^6 cm^{-2}s^{-1}$$

$$\phi(\nu_\mu, \nu_\tau) = (3.41_{-0.45-0.45}^{+0.45+0.48}) \times 10^6 cm^{-2}s^{-1}$$

and calculated in this work elastic neutrino-electron cross-sections

$$\sigma_{\nu_e}^{B-8} = 5.96 \times 10^{-44} cm^2,$$

$$\sigma_{\nu_{\mu,\tau}}^{B-8} = 7.83 \times 10^{-45} cm^2.$$

We obtain the expected number of events for 1 ton of ^{76}Ge target (isotopically enriched to 86 % in ^{76}Ge) per year

$$R_{\nu_e}^{B-8} = 0.84 \text{ events}/(t \cdot y),$$

$$R_{\nu_{\mu,\tau}}^{B-8} = 0.22 \text{ events}/(t \cdot y).$$

Calculation of count rate for pp and 7Be neutrinos

$$R^{pp} = 581 \text{ events}/(t \cdot y)$$

$$R^{Be-7} = 229 \text{ events}/(t \cdot y)$$

for fluxes from the Solar Standard Model [16]

$$\phi^{pp}(\nu_e) = (5.94 \pm 0.01) \times 10^{10} cm^{-2}s^{-1}$$

$$\phi^{Be-7}(\nu_e) = (0.48 \pm 0.09) \times 10^{10} cm^{-2}s^{-1}$$

have been performed and then compared with those ones from [7]

$$R^{pp} = 658 \text{ events}/(t \cdot y)$$

$$R^{Be-7} = 219 \text{ events}/(t \cdot y).$$

Since pp neutrinos have a continuous energy spectrum with endpoint at 0.42 MeV and 7Be neutrino from $^7Be + e^- \rightarrow ^7Li + \nu_e + \gamma$ reaction yields a monoenergetic line at 0.862 MeV, elastic scattering of these neutrinos can not give events into ROI.

The experiments under consideration are supposed to consist of an array of about 300 HPGe detectors, with mass ≈ 3 kg each, and the sensitive volume divided into 12 separate cells to discriminate background since neutrino interaction is taking place in a single cell.

Recoil electron energy deposition for these experiments for a single Ge detector was performed with GEANT 3.21 package [19], as well as background caused by scattering of 8B solar neutrino on electrons of Ge detector in ROI is $B_{ROI} = 4.6 \times 10^{-4}$ counts/(keV·t·y).

In the experiments HPGe detectors are placed in some cool medium, such as liquid nitrogen or liquid argon, or copper. The medium can contribute to background due to recoil electrons from solar neutrino electron scattering in the media. Calculations for liquid nitrogen to be used in GENIUS experiment were done. The background is 4.5 % of that of Ge detectors given above.

Antineutrino flux from nuclear power plant reactors being $\phi_{\bar{\nu}_e} \approx 4 \times 10^6 \bar{\nu}_e \times cm^{-2} \times sec^{-1}$ yields background of 2.3×10^{-5} counts/(keV·t·y), which is 11% of B_{ROI} .

(The antineutrino flux value taken above is that of the KamLAND experiment's place).

Calculations to define contribution due to geo antineutrinos was estimated too, it is about 0.9 % of B_{ROI} [20].

Similar calculations for liquid xenon 10 tons detector were performed.

The count rate of ES events could be given

$$R_{ES} \approx (1.1 \times 10^{-3}/(keV \cdot t \cdot y))(ROI \frac{M}{M_{mol}} N_e) \quad (7)$$

M - is mass of detector in tons, M_{mol} - is target molecular weight, ROI is energy region width in keV, N_e - is number of electrons in target molecule.

For 400 kg of ^{136}Xe , neutrinoless double beta decay with $T_{1/2}^{0\nu} = 4. \times 10^{27}$ y will give ≈ 0.3 counts per year. From formula (7) for 10 tons xenon detector the ES count rate is same.

As EXO project cannot be able to reconstruct the tracks of the emitted electrons, the background due to

ES will not be rejected. So the sensitivity is $T_{1/2}^{0\nu} \approx 4. \times 10^{27}$ years.

Using (3) and taking nuclear structure factor $F_N = G^{0\nu} \times M_{0\nu}^2 = 1.18 \times 10^{-13} y^{-1}$ from [21] we can obtain sensitivity in terms of effective majorana neutrino mass:

$$|< m_{\nu_e} >| = \frac{m_e}{\sqrt{F_N \times T_{1/2}^{0\nu\beta\beta}}} = 23.5 \text{ meV}. \quad (8)$$

In Fig.1, one can see three energy spectra in the ROI, namely, the two electron sum spectrum of ^{136}Xe ($2\beta 2\nu$) ^{136}Ba decay with $T_{1/2}^{2\nu} = 2.0 \times 10^{22}$ y; the calculated recoil electron spectrum $\nu + e^- \rightarrow \nu + e^-$ for neutrinos from $^8\text{B} \rightarrow 2\alpha + e^+ + \nu_e$ solar reaction, and the third one is the expected peak, corresponding to $^{136}\text{Xe}(0\nu\beta\beta)^{136}\text{Ba}$ decay with $T_{1/2}^{0\nu} = 4.0 \times 10^{27}$ y and $\text{FWHM}(2480 \text{ keV}) = 60.0 \text{ keV}$.

Similar situation is shown for case ^{76}Ge with $T_{1/2}^{2\nu} = 1.74 \times 10^{21} \text{ y}$ [11] and $\text{FWHM}(2039 \text{ keV}) = 5.0 \text{ keV}$ in Fig2. But in this case, the contribution of ES events is only 2%.

To summarize, for the planned experiments with detectors enriched in ^{76}Ge with mass upto ≈ 10 tons, the background from elastic scattering of solar neutrinos could be considered as negligible.

For experiments with mass of ≈ 10 tons and resolution of tens keV, such as EXO or XMASS, this background channel though by its universal character restricts sensitivity of double beta decay experiments at a level of $T_{1/2}^{0\nu\beta\beta} \approx 4. \times 10^{27}$ y or the same, in terms of effective majorana mass, $|< m_{\nu_e} >| \approx 23.5 \text{ meV}$.

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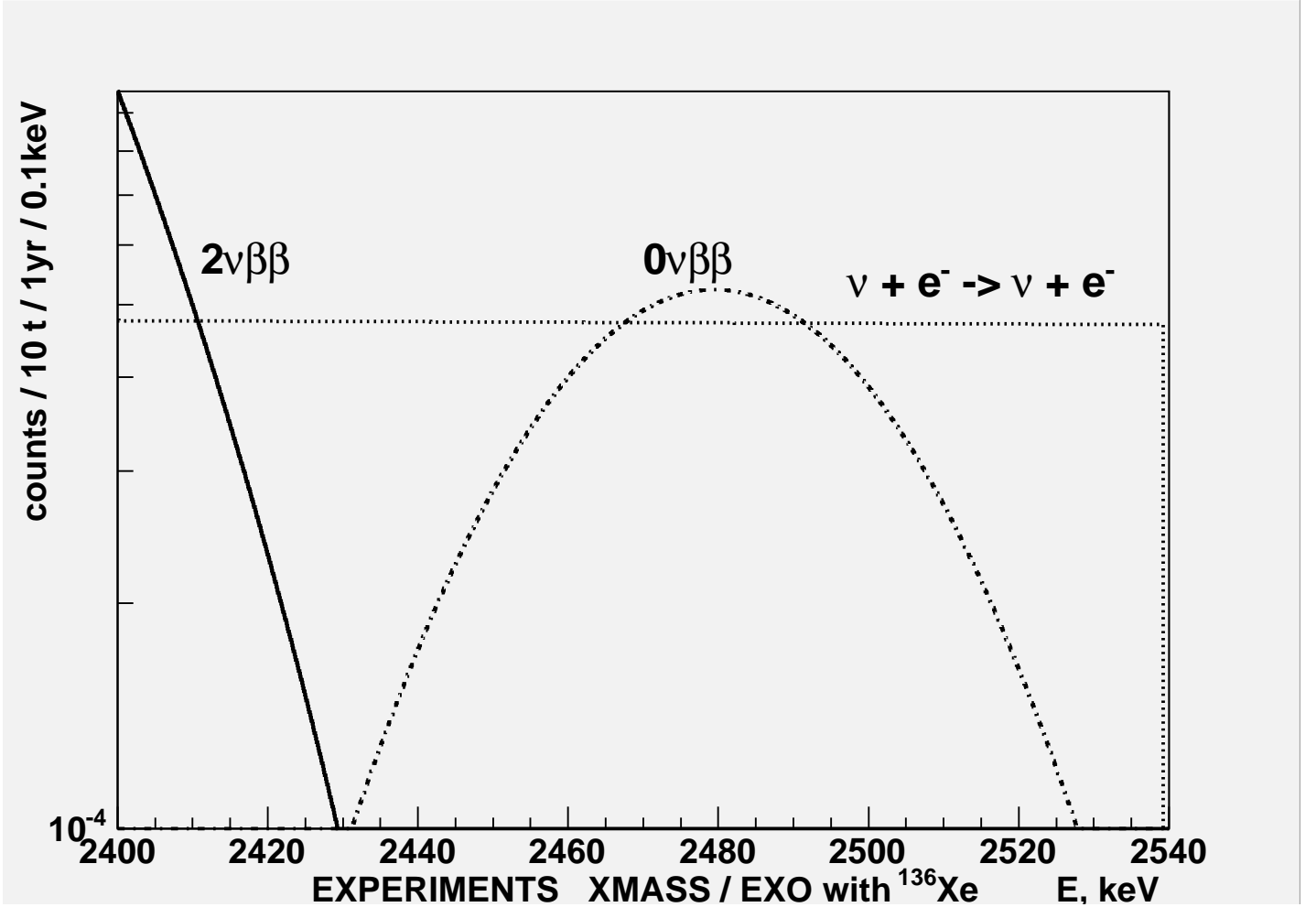


Fig.1. Spectra in the vicinity of ROI of $^{136}\text{Xe}(0\nu\beta\beta)^{136}\text{Ba}$ decay. Solid line is two electron energy sum spectrum of $^{136}\text{Xe}(2\beta 2\nu)^{136}\text{Ba}$ decay with $T_{1/2}^{2\nu} = 2.0 \times 10^{22}$ y. Dotted line is calculated recoil electron spectrum $\nu + e^- \rightarrow \nu + e^-$ for neutrinos from $^8\text{B} \rightarrow 2\alpha + e^+ + \nu_e$ solar reaction. Dash-dot line is expected peak, corresponding to $^{136}\text{Xe}(0\nu\beta\beta)^{136}\text{Ba}$ decay with $T_{1/2}^{0\nu} = 4.0 \times 10^{27}$ y and $\text{FWHM}(2480 \text{ keV}) = 60.0 \text{ keV}$.

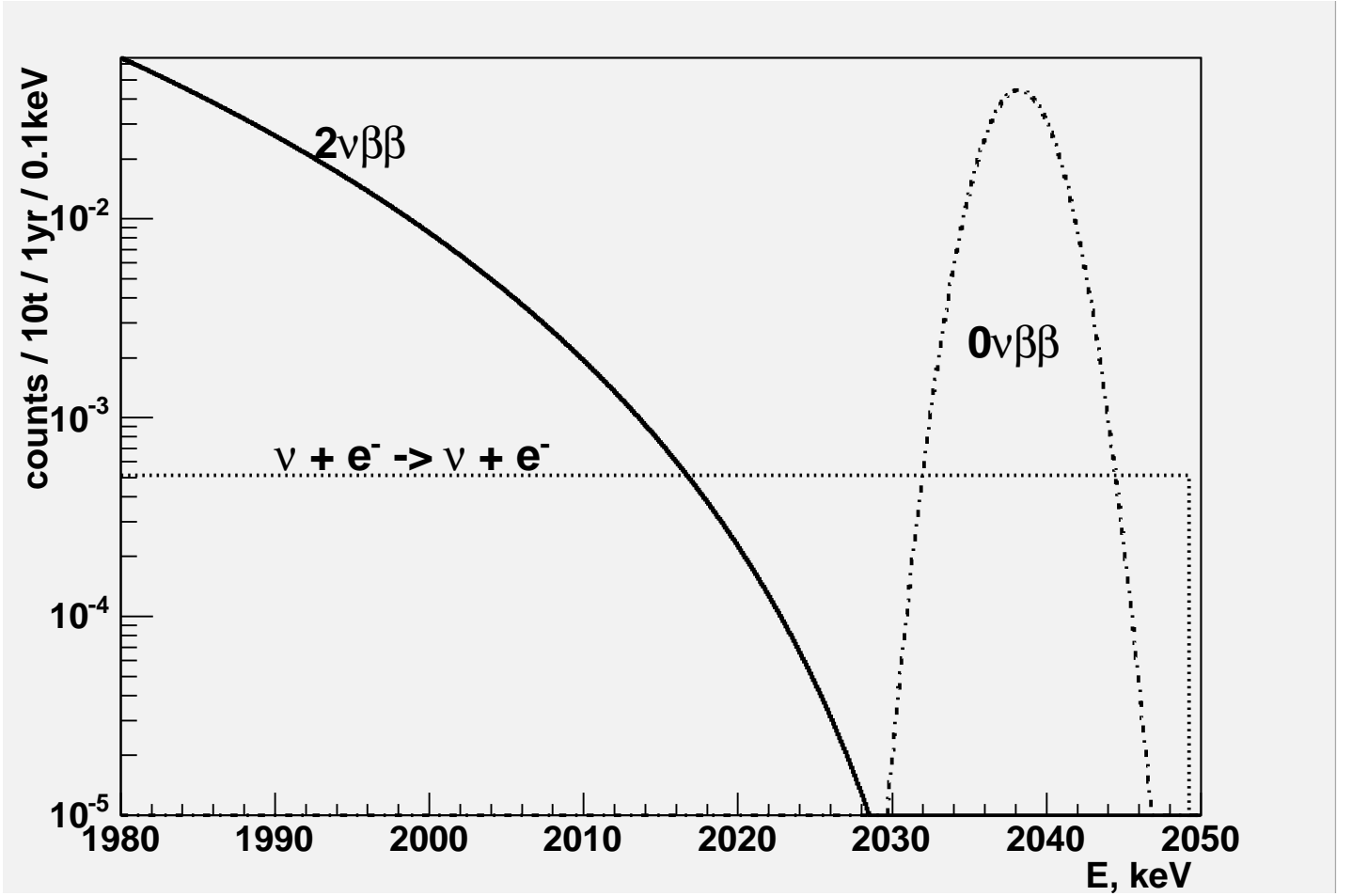


Fig.2. Spectra in the vicinity of ROI of $^{76}\text{Ge}(0\nu\beta\beta)^{76}\text{Se}$ decay. Solid line is two electron energy sum spectrum of $^{76}\text{Ge}(2\beta 2\nu)^{76}\text{Se}$ decay with $T_{1/2}^{2\nu} = 1.74 \times 10^{21}$ y. Dotted line is calculated recoil electron spectrum $\nu + e^- \rightarrow \nu + e^-$ for neutrinos from $^8\text{B} \rightarrow 2\alpha + e^+ + \nu_e$ solar reaction. Dash-dot line is expected peak, corresponding to $^{76}\text{Ge}(0\nu\beta\beta)^{76}\text{Se}$ decay with $T_{1/2}^{0\nu} = 4.2 \times 10^{27}$ y and $\text{FWHM}(2039 \text{ keV}) = 5.0 \text{ keV}$.